

# ERGONOMIC DESIGN OF CONTROLS, DISPLAYS, AND WORKSPACE ARRANGEMENTS TO REDUCE HUMAN ERROR

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## AN OVERVIEW OF HUMAN FACTORS/ERGONOMICS (HF/E)

Perhaps the most widely used descriptive definition of human factors – or ergonomics as the discipline alternately is known – is that of Chapanis, (1988): *Ergonomics* is a body of knowledge about human abilities, human limitations and other human characteristics that are relevant to design. *Ergonomic design or engineering* is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable and effective human functioning.

### *The Technological Context of Human Factors/Ergonomics*

Any scientific discipline can most readily and distinctly be defined by the nature of its unique technology. Based on its survey of human factors/ergonomics internationally, the Strategic Planning Committee of the HFES identified the unique technology of human factors/ergonomics (HF/E) as *human-system interface technology* (Human Factors and Ergonomics Society, 2001). Included are the interfaces between the people portion of systems and the other sociotechnical system components. These components include jobs, hardware, software, internal and external environments, and work system structures and processes. As a *science*, HF/E involves the study of human performance capabilities, limitations, and other characteristics. These data then are used to develop human-system interface technology (HSIT). HSIT takes the form of interface design principles, guidelines, specifications, methods, and tools. As a *practice*, HF/E professionals apply HSIT to the design, analysis, test and evaluation, standardization, and control of systems. The over-all goal of the discipline is to improve the human condition, including health, safety, comfort, productivity and quality of life.

HSI technology has at least five clearly identifiable sub-parts, each with a related design focus (Hendrick, 1998, 2001). These are as follows.

1. *Human-machine* interface technology or hardware ergonomics.
2. *Human-environment* interface technology, or environmental ergonomics.
3. *Human-software* interface technology, or cognitive ergonomics.
4. *Human-job* interface technology, or work design ergonomics.
5. *Human-organization* interface technology, or macroergonomics.

This paper focuses on an overview of the first of these areas, human-machine interface technology or hardware ergonomics, with particular emphasis on the design of controls, displays and their arrangement to reduce human error and enhance performance and safety.

### *The Beginning of a Formally Recognized Discipline of Human Factors*

Although some of the underlying research can be traced directly back to the late 19<sup>th</sup> and early 20<sup>th</sup> centuries, human factors, as an identifiable area of research and practice, began in the 1940s during World War II. In the United States, England and Germany, human factors research and application was conducted to enhance human performance in military weapons systems. For example, all three countries were concerned with how to improve the design of gun sights in order to enable the human to use them more accurately, given human perceptual and psychomotor capabilities and limitations.

In the United States, engineering psychologists were called upon to investigate military aircraft accidents to try and better understand why so many of them were being attributed to “pilot error”, and to gain a better understanding of what “pilot error” really meant from a causation standpoint. The basic finding was that what was being called “pilot error” really was *engineering design error*. Put simply, the controls, displays and workspace arrangements were being designed in ways that were not compatible with human capabilities and limitations. Consequently, these designs were causing pilots to make errors. For example, a pilot would learn to fly in one aircraft, with the altimeter and other critical flight instruments having a particular arrangement on the instrument panel, and then transition into another aircraft with an entirely different arrangement, thus inducing negative transfer of training errors – particularly under stressful flight conditions. During the first two years the US was involved in World War II, over 2000 major multi-engine aircraft accidents were caused by the landing gear and flap leavers being identical in shape, size, and method of operation, and located too close together to permit identification through kinesthetic feedback. Consequently, when landing the aircraft while peering out the window, the pilot, relying on touch and kinesthetic feedback rather than visual inspection, often would mistake one control for the other.

In the US, these findings led to research to better understand the *human factors* involved in designing human-machine interfaces and, hence, to the development of human factors as an identifiable area of research and application. Initially, the central focus was on human perception, reaction, and learning factors and the use of laboratory studies as a means of developing what then was called *man-machine interface* technology. For example, a classic laboratory study was done by the US Air Force human factors researchers to determine the best combination of control shapes to use in aircraft crew stations for the various flight functions to facilitate identification of a given control and discriminating it from the others. The results of this study, which made use of control shapes associated with the function where possible, led to the standardization of aircraft controls that is used throughout the world today. Similar laboratory research in the late 1940s and 1950s led to the identification of the instruments most critical to flight and an optimal standardized arrangement of them that remains in use today. These efforts have resulted in a huge reduction in design induced pilot errors and concomitant improvements in aviation safety. (American Psychological Association, undated)

The success of human factors research and application in the aviation industry led to the discipline’s expansion to motor vehicle transportation systems during the 1960’s. During the

1970's we saw the human factors discipline further broaden to many other areas of application to improve safety and usability – a trend that continues today.

In summary, the first several decades of human factors as an identifiable discipline were characterized by laboratory studies to identify the human factors relevant to design; and using the results of that research to develop a human-machine interface technology that could be applied to the design of controls, displays, and workspace arrangements. The central focus was on human perceptual, learning, workload, and psychomotor capabilities and their design implications. The initial application of this human-machine interface technology was to the design of aircraft and motor vehicle ground transportation systems.

### *The Beginning of a Formally Recognized Discipline of Ergonomics*

As a clearly identifiable discipline, ergonomics really began after the Second World War. Following World War II, Europe and Japan were faced with the task of rebuilding their factories. As a result, a concern developed over how to systematically study the nature of human work, or *ergonomics* (from the Greek *ergo*, for work, and *nomos*, meaning the study of), and then apply that knowledge to the design of workplaces. Although cognitive factors also were of concern, the central focus was on the physiological, anthropometric, and biomechanics characteristics of humans, and the use of systematic field observation studies to develop an ergonomics technology related to the physical and environmental aspects of work.

### *The Convergence of Ergonomics and Human Factors*

At least through most of the 1960's, the central focus of human factors and ergonomics could be contrasted as follows.

1. Human Factors relied primarily on laboratory studies while ergonomics relied primarily on field studies.
2. Human Factors primarily was concerned with the perceptual, learning, and psychomotor aspects of human performance, whereas ergonomics primarily was concerned with the physiological, anthropometric, and biomechanical aspects of human performance.
3. Human Factors technology primarily was applied to the design of transportation systems, whereas ergonomics primarily was applied to the design of industrial workplaces.
4. Human factors professionals primarily had an educational background in psychology, whereas ergonomists typically had an educational background in physiology, engineering, medicine, or the rehabilitation disciplines.

At the same time, there also was significant overlap of the two disciplines during their early years. For example, human factors researchers also did study human physical, biomechanical and anthropometric characteristics, and apply the resulting technology to design. Ergonomists also did study human perceptual, learning, and psychomotor characteristics, and apply the resulting technology to design. Some human factors professionals were trained in engineering or medicine and some ergonomists were trained in psychology. Thus, as Chapanis noted in 1971, the differences between human factors and ergonomics primarily were ones of emphasis. While many factors have contributed to the convergence of human factors and ergonomics,

increased awareness and concern about occupational safety and health clearly was a major factor. Today, the terms “ergonomics” and “human factors” are used interchangeably.

## THE HUMAN-MACHINE SYSTEM

The human-machine system consists of an *operator* who senses input information about the systems condition. This information usually is provided by the *machine* portion of the system in the form of a visual or auditory *display*. The operator mentally processes the input from the display, and then, as required, initiates some appropriate machine action by manipulating a *control* on the machine. Critical to safe, effective system performance is the design of the two major human-machine interfaces: The *display*, which provides the operator with necessary information, and the *control*, which the operator uses to cause some appropriate machine action. If the display is not designed in a way that matches human sensing and perceptual capabilities, the operator is likely to make reading or interpretation errors and, thus, take an inappropriate action. If the control is not designed in a way that matches human control capabilities, the operator may over or under control the system. Errors arising either from poor display design or poor control design can lead to accidents and injuries, as well as to poor system performance. In addition, *where* specific controls or displays are positioned in the operator’s work area, such as their location and arrangement on a control-display panel, also can either enhance performance or impede it and induce human error.

One of the early decisions to be made in the design of a human-machine system is which functions to allocate to humans and which to the machine to perform.

### *Function Allocation*

Historically different approaches have been taken to function allocation. The first was the “machine as mule” approach, in which the machine was regarded as a dumb item to be fully controlled by the human. Later, with the advancement of automation, a techno-centered approach often has been taken in which all functions that could be assigned to the machine first were made, and what ever was left over was assigned to the human – such as passively monitoring the machine. Unfortunately, this approach often leads to a failure to take maximum advantage of human capabilities and results in dehumanized jobs with little or no intrinsic motivational characteristics.

In recent decades, a complementary, *human-centered* approach has been taken in which designers first ask, “What functions or tasks need to be done by humans – what fits their capabilities?” And then assigns those functions to humans. The machine then is assigned functions to complement the human – functions that a machine can more accurately and effectively perform than a human. In considering human and machine capabilities in allocating functions or tasks, the following can be useful to keep in mind.

### *Human Capabilities*

Although there can be many exceptions, depending on the specific nature of the machines and tasks involved, in general, humans have been found to be superior to machines in accomplishing the following.

1. Sensing very low levels of stimuli
2. Detecting signals in a high-noise background.
3. Recognizing patterns in complex stimuli, such as language.
4. Retrieving related items of information from memory.
5. Adapting decisions to situational requirements.
6. Developing entirely new solutions.
7. Adapting responses to changes in operational requirements.

### *Human Limitations*

Among human limitations, the following are ones that machines often accomplish more effectively.

1. Sensing energy outside of a fairly restricted range.
2. Monitoring for infrequent events.
3. Applying physical force with precision.
4. Sensing very gradual changes in stimuli.
5. Performing highly repetitive tasks reliably.
6. Performing several activities at once.
7. Working continuously over long periods.

Once an initial allocation of functions has been accomplished, the job is rarely done. Typically, function allocation is an iterative process in which refinements will be made as the design and development of the system progresses.

### *Identifying User Information Requirements*

After allocating functions, a next step is to identify what types of information the user needs and the kinds of things s/he will need to control. Once the information and control requirements are known, the types of displays and controls that will be needed can be determined.

## HUMAN-MACHINE INTERFACES: CONTROLS

Controls come in a wide variety of types. Some of the more common hand controls are toggle switches, rotary switches, push buttons, knobs, levers, wheels and sticks. The most common foot controls are pedals and push buttons.

### *Control Selection*

The type of control used for a specific purpose within a system should depend on several factors.

1. *The nature of the task.* For example, does the control task involve making continuous movements – such as controlling the amount of fuel going to a vehicle engine for acceleration or deceleration – or simply turning a component “on” or “off”.

2. *The amount of precision required.* This is important to all continuous movement controls and what they are controlling. A key factor here is the *control-response ratio*, discussed later. For discrete controls, the amount of precision required determines the number of discrete settings that must be provided by the control. For example, a light switch might require just two settings, “on” and “off”. On the other hand, perhaps five different levels of lighting are needed, thus requiring a control with five discrete settings in addition to “off”. If even more precision were required, a continuous dimmer switch might be needed.
3. *The amount of force required.* If a large amount of force must be applied by the control, then a lever that provides a large mechanical advantage may be needed. Alternately, a hydraulically or electrically activated system may be required, so that the control need not have a large mechanical advantage. Power steering in an automobile is a good example of such a system.
4. *Discrimination from other controls.* When more than one control is to be used at a given operator station, it is extremely important to ensure that each control can be discriminated from the others. Failure to do this early in World War II aircraft was a major source of aircraft accidents. For example, I noted earlier that during the first two years of that war, over 2,000 multi-engine U.S. aircraft crashed because the landing gear and wing flap controls could not be discriminated from one another by location (close together, side-by-side), feel (had the same shape and size), or direction of movement (moved the same way). The pilot, looking out the windscreen and feeling for the controls while landing the airplane, would thus make mistakes. This led to a human factors study to identify the basic set of controls required in all aircraft; and then to the ergonomic development and standardization of a series of shapes for these controls that readily could be discriminated from one another. With the implementation of this standardized set of controls, aircraft accidents caused by a lack of control discriminability were virtually eliminated. Accidents in industry also occur because of a lack of control discriminability.

Common ways of enabling control discrimination are by (a) shape, (b) size (relatively large medium, and small), (c) texture (smooth, fluted, and knurled, but no more than one of each type of texture for discrimination purposes), (d) direction of movement, and (e) location (at least 5 inches apart when relying on kinesthetic feedback for location discrimination). Color-coding also is frequently used for control discrimination in situations where the operator is able to look at the controls when operating them – and no operator of the controls is colorblind.

Very often, redundant means are used to facilitate control discrimination. For example, a control might differ from others in both shape and texture, or in location and direction of movement, etc. Wherever practical, redundant coding strongly is recommended.
5. *Identification with function controlled.* Where feasible, designing or choosing a control shape that readily is identified with the function being controlled is strongly advised, as it facilitates the operators task and reduces the likelihood of choosing the wrong control. In the World War II aviation example noted above, the landing gear control was redesigned

in the shape of a wheel and the wing flap control was redesigned in the shape of a wing flap.

6. *Identification of the function controlled with a particular control type.* Past experience may have associated a particular control type or shape with a given control function for the operator(s). This is known as an *occupational stereotype*. In general, in order to avoid negative transfer of training/experience effects (discussed later), it is a good idea not to violate occupational stereotypes in choosing a control for a given function.

### *Movement Compatibility*

In our society and much of the world, the direction of movement of many controls has become associated with particular movements of the system. The most common are as follows.

1. *Up:* On, Start, High Speed, Increase, Open, Engage, Forward, Positive.
2. *Down:* Off, Stop, Low Speed, Decrease, Close, Disengage, Reverse, Negative.
3. *Clockwise:* On and Increase (for current), Off and Decrease (for fluids), Turn/Move Right.
4. *Counter Clockwise:* Off and Decrease (current), On and Increase (fluids), Turn/move Left.
5. *Forward:* Increase (for energy control of vehicles).
6. *Push Down:* On floor pedals, is associated with Increase (for current or speed).

Movement compatibility not only applies to compatibility of a control with the function being moved, but also compatibility with the movement of the affected display. In most cases, when the control increases a system parameter, the corresponding analog display should move up, clockwise, or from left to right. With fixed scale moving pointer displays (e.g., a car speedometer) the pointer moves up or from left to right for Increase) With fixed pointer moving scale displays, the scale moves down or from right to left for Increase, which gives the illusion of the pointer moving up or right. With digital displays, of course, the digital number will increase or decrease as the related parameter being controlled increases or decreases.

### *Physical Compatibility*

In many situations, it is extremely important that the movement of the control be compatible with that part of the system that it is physically moving. For example, if the control is moving some part of the system forward, such as the arm of a crane, the movement of the control also should be forward. Similarly, moving the control stick in an airplane forward and down makes the plane's nose dip down; pulling back on the stick makes the nose lift up. In an experiment, I once reversed the controls in a flight simulator so that pushing forward and down on the control stick

made the “airplane’s” nose go up; moving the stick to the right made the plane go left, and visa versa. Experienced pilots’ error rates went up 400%, and one subject pilot “crashed”.

A second aspect of physical compatibility has to do with the grouping of similar controls to match the physical layout of the things they are controlling. For example, in a two-engine airplane, the two throttles are placed side-by-side, with the left throttle controlling the engine on the left wing of the aircraft and the right throttle controlling the engine on the right wing. Note that it also is important to arrange the displays associated with these controls to also match the physical arrangement of the controls and the things being controlled.

### *Control/Response Ratio*

For analog controls, such as the throttles of an airplane, the control response (C/R) ratio is critical. If the control moves a long distance for a small system change, the C/R ratio is small, indicating a relatively insensitive control – one that enables very precise small system changes by the operator. If a small control movement results in a large system change, than the C/R ratio is high, indicating a relatively sensitive control. Too insensitive a control does not enable the operator to make required changes quickly enough; too sensitive a control does not enable the operator to make small, precise changes.

When I worked on the development of the Air Force C-141 transport aircraft, the aircraft’s engines were so powerful that, when the plane was lightly loaded, a small increase in the movement of the throttles resulted in a large change in the aircraft’s speed. The C/R ratio was too high for the pilot to be able to make small, precise changes in the aircraft’s speed. As a result, the throttle system had to be redesigned to reduce the C/R ratio. Similar problems can occur with equipment in industry, such as the C/R ratio for crane controls.

### *Arrangement/Grouping and Location of Controls*

Controls often are grouped. For example, controls controlling identical functions, such as the throttles on a multiengine aircraft, are grouped together. When a series of controls control a sequence of actions, they should be grouped and arranged in the order in which they are to be activated. Where and how a set of controls is grouped also can be based on occupational stereotypes (i.e., with their associated location and arrangement from past operator experience).

In general, the most important and/or most frequently used controls should be placed where they are most easily accessible to the operator. Relatively unimportant or infrequently used controls can be placed in less accessible locations. For example, the controls for operating the major functions of an aircraft are placed either directly in front of the pilot or close to the pilot’s side where they are easily reached. Infrequently used controls, such as circuit breakers, may be on a panel that is not readily reached by a crewmember from his or her seated workstation position. Less important controls, such as those for lights, may be on the pilot’s overhead panel.

Although they may not be important to system functioning, some frequently used controls should never-the-less be placed in a convenient position (and appropriately designed) where they will not distract the operator from his primary tasks – particularly where that distraction could result in an accident. A good poor example of this principle is the location of the radio controls in many automobiles. They tend to be on the radio, low down, and well to the driver’s right (in cars made for the U.S. market). Often the controls are small, not readily



distinguishable from their background, similar to one another so they are difficult to discriminate by touch, and have small labels that are too small to read (without bending down close to the radio) or labels lacking contrast with their background (so not readable without bending down close to the radio). It thus is not surprising that a major cause of car accidents is drivers diverting their attention from driving to the car radio in order to adjust the controls.

A final consideration is the spacing of grouped controls. It is important to allow sufficient room between controls so that the operator will not inadvertently activate one while operating the intended control. When I worked on the design of the Dynasoar space vehicle, we had to space the controls further apart than for an aircraft crew station control panel in order to accommodate the astronaut wearing a pressurized space suit with its large clumsy fingers (the Dynasoar was the Department of Defense counterpart to the NASA Gemini space vehicle and looked like a small space shuttle. It eventually was cancelled in favor of the Gemini program because of the expense).

## HUMAN-MACHINE INTERFACES: VISUAL DISPLAYS

### *Quantitative and Qualitative Displays*

Most dynamic displays are either *quantitative* or *qualitative in nature*. Quantitative displays are used to give the state of the system with precision. Typical examples are temperature gauges and car speedometers. Quantitative displays may be either analog, such as an automobile speedometer, or digital, such as a car odometer. Qualitative displays are used to determine the “quality” of the system without knowing the exact value. For example “safe”, “caution”, “danger”, or “operational”, “standby”, “inoperative”. Not infrequently, a quantitative analog display and a qualitative display may be combined. For example, the tachometer in a car may have the safe RPM range marked by a green stripe on the instrument perimeter, the caution range marked in yellow, and the danger range marked in red. This gives the operator the choice of either check reading his tachometer to see in which range the car engine’s current RPM falls, or reading his tachometer quantitatively to determine the actual RPM. Since check reading can be done more quickly than quantitative reading, this capability is particularly useful when the operator must attend to other things, such as steering a car and looking out the window, or operating a piece of complex machinery.

### *Tracking Displays*

Tracking displays are of two general types: *Pursuit* displays show the position of both the target object(s) being pursued, and the object doing the pursuing, being controlled by the operator. For example, a display in a combat operations room might be a map that shows a plan view of the position and direction of the enemy aircraft and of the friendly fighter aircraft pursuing them.

The second type of tracking display is the *compensatory* display. The radar fire control system display in a fighter aircraft is a good example. The fighter aircraft position is in the middle of the screen; the target being pursued is represented by a moving dot on the screen. The fighter pilots job is to steer his airplane in such a way as to cause the moving dot to move to the center of the screen. . The further away the dot from the center of the screen the more the pilot must correct the fighter plane’s direction to get it lined up with the target aircraft. Once that happens, the fighter pilot can “lock on” to the target and shoot it down. My first human factors

research project was as an undergraduate assistant on an Air Force research contract to determine how much force felt natural for a human to apply to a control stick to compensate for various amounts of deviation of the moving dot from the center of the compensatory display. We found that humans were quite consistent in their judgments and we were able to mathematically compute the force curve to be designed into fighter aircraft control sticks for maximum pilot accuracy.

### *Static Displays*

Static displays provide information that does not change on the display. Such displays may be words, numbers or symbols, depending on their purpose. Common types are as follows.

1. *Information displays.* These displays often are signs to provide the reader with needed information. Typical examples are street signs (numerical or words), signs showing arrows indicating what direction to go, road signs showing speed limits (numerical), signs indicating a hospital (words and symbol).
2. *Caution display.* These displays are used to alert the individual to a caution condition, which, if ignored, could result in equipment damage or possible injury to someone. Typically, these signs have black lettering on a yellow or yellow-orange background, or sometimes, yellow or yellow-orange lettering on a black background. They usually begin with the signal word, "Caution".
3. *Danger display.* These displays typically have a red background with white lettering. They are used to indicate conditions that, if ignored, are highly likely to result in serious injury or death. They usually begin with the signal word, "danger".

Static displays can be effective provided they are well maintained (even partial degrading of the paint or failure to keep them clean will greatly degrade their effectiveness). To be effective these displays should have (a) a large contrast between the information and the background, (b) Use block letters for maximum readability, (c) Except for the signal word, capitalize the first letter only of each phrase or sentence, (d) be kept as short and concise as possible for clearly conveying the message, (e) use letters, numbers or symbols that are large enough to be read easily – even by persons with somewhat degraded visual acuity. Specific guidelines for preparing static displays can be found in human factors and safety handbooks.

When preparing caution or warning signs, the prototype sign should be tested to see if (a) it captures peoples' attention in its intended use environment, (b) informs people of the caution or hazard, and (c) indicates what one is to do in response to the caution or warning. Not infrequently, what seems to the designer to be a well-designed caution or warning display turns out not to be effective when put to a realistic test. It therefore may take several design iterations before one comes up with a design that proves effective.

### *Design Guidelines for Quantitative Analog Displays*

The quantitative analog displays we are most familiar with are round dial instruments, such as clocks and car speedometers. Another common design is the horizontal display, which

also sometimes is used for car speedometers. Still another is the vertical display. These can either be fixed scale moving pointer, fixed scale thermometer, or fixed pointer moving scale in design. Finally there are the window type instruments where only a portion of a circle is displayed. Some car temperature gauges and battery gages are of this type.

For automobile, aircraft, and other operator stations, many quantitative displays are designed for a 28-inch viewing distance. If the actual viewing distance is more than a couple of inches greater, display readability will be significantly degraded. In those cases, either the work station should be redesigned to shorten the viewing distance, or displays with larger numbers and markers should be used.

Some of the most common design specifications for fixed scale moving pointer displays are as follows.

1. *Numeric progression.* The numeric progression of the scale ideally should be by 1s (0, 1, 2, 3, etc.). This progression readily lends itself to a scale with major markers at 0, 10, 20, etc. with intermediate markers at 5, 15, 25, etc. For best clarity, only the major scale markers also have numerical designators. Progression by 5's also is satisfactory, and by 2's is acceptable where appropriate. Unusual progression systems (e.g., by 3's, 8's, etc.) should not be used as they greatly degrade readability and cause confusion.
2. *Scale marker dimensions.* Specifications for the length and width of major, intermediate, and unit markers can be found in human factors and ergonomics textbooks and handbooks [e.g., Sanders and McCormick (1993); Woodson, Tillman, & Tillman (1992)]. In general, the smallest scale marker should represent the greatest precision to which the system is capable of being controlled and of which the instrument is capable of portraying accurately. For example, if the display indicates compass direction to the nearest degree of azimuth, but the instrument is only accurate to + or - 2 degrees, then it would be more appropriate to have each marker indicate a 5 degree change.
3. *Scale pointers.* Research has shown that a simple pointer with a tip angle of approximately 20 degrees works best, with the tip of the pointer just reaching (but not overlapping) the end of the smallest scale marker. Also, to avoid parallax, the pointer should be as close to the display face as possible. This is especially important for avoiding reading errors when the scale is viewed from an angle, rather than straight on.
4. *Multiple pointers.* Using multiple pointers on the same scale generally should be avoided. For example, if a person is required to mentally integrate the information from two or three pointers in order to derive the composite quantitative reading, such as in conventional round dial aircraft altimeters, the task will take time and even trained pilots will make reading errors – especially when under a high workload demand.

Using two pointers on the same round dial display to indicate the status of two identical systems can be done, but usually is not ideal as there is the danger of confusing which pointer refers to which system – particularly if the operator is under a high task load or time pressure. I once investigated an accident where this design induced confusion was determined to be the cause.

## *Arrangement and Grouping of Displays*

There are four primary principles of arrangement for locating and arranging displays on a workstation panel. Two of these apply for determining the general location for a given display. The other two principles apply to determining the specific arrangement within the general location.

### *Determining general location on a panel*

1. *Importance of use.* The most important displays should be located in the central portion of the control panel.
2. *Frequency of use.* The most frequently used displays should be located in the central portion of the control panel.

### *Determining the arrangement within a given panel location*

3. *Group by function.* Those displays that pertain to the same function should be grouped together.
4. *Arrange by sequence of use.* Displays should be arranged in the order in which they typically are scanned.

In addition, as discussed earlier, physical compatibility of the display arrangement with what they refer to, and with the controls they are associated with, can be an important factor in determining the display arrangement. Figure 1 shows the alignment of the engine parameter instruments for a four-engine airplane. Each column of instruments represents the parameter instruments for a single engine. The engine 1 column represents the outboard engine on the left wing, column 2 the left inboard engine, column 3 the inboard right wing engine, and column 4 the right outboard engine. They thus have good physical compatibility with what they represent, thereby greatly reducing the likelihood of mistaken association and the resultant potential error.

Note that for grouped instruments, the neutral or normal position of the pointers should be arranged in the same direction – preferably at the 12-o'clock position. The 3-o'clock position also may be desirable for some applications. Note that aligning the pointers makes the displays much easier for check reading. Also, by comparing the displays for a single parameter across engines, it is immediately obvious if one engine is out of alignment on that parameter. This makes it very easy to quickly diagnose a problem.

# **Engines**

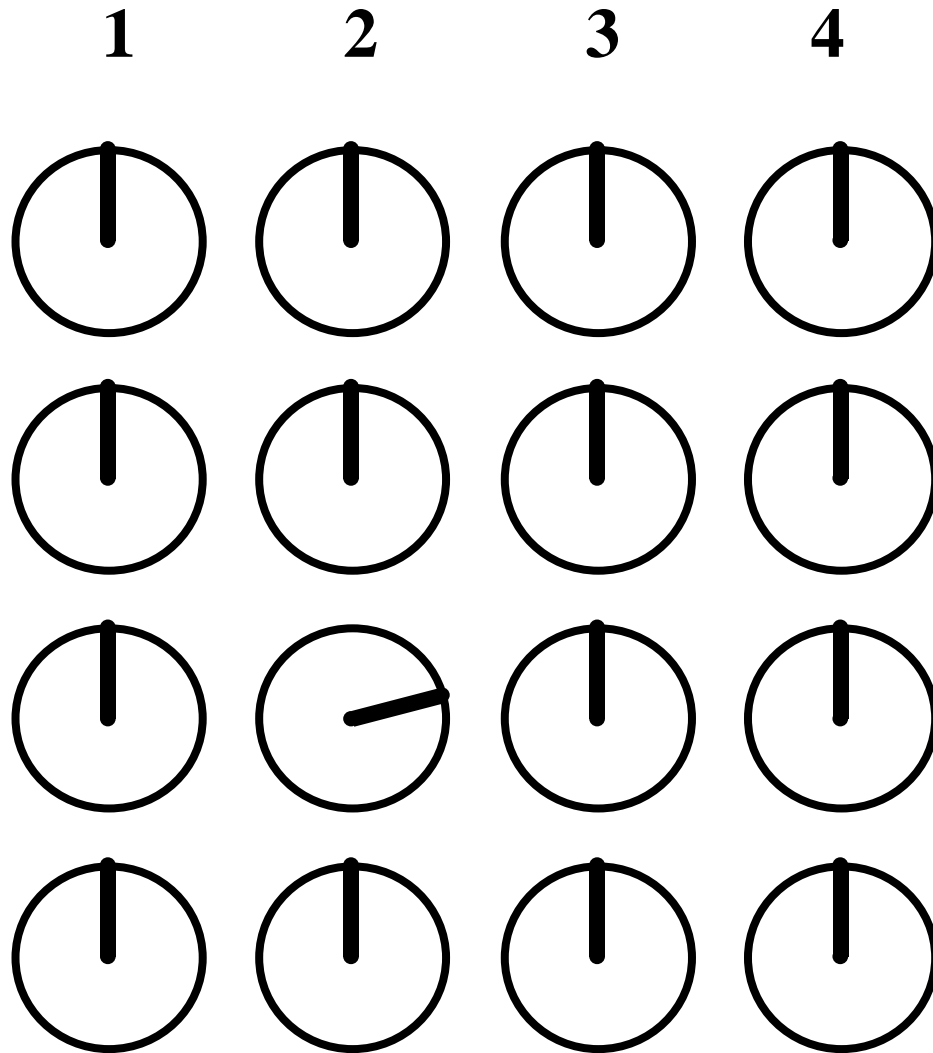


Figure 1. Engine parameters instruments for a four engine airplane.

### *Labeling of Control-Display Panels*

*Principle 1: Place labels above item.* In general, labels on control-display panels should be placed immediately above the switch or instrument to which the label applies. This does two things: First, it makes it very clear as to which control or switch the label applies. Second, when the operator reaches for a switch, his hand will not cover up the label (which would happen if the label was below the switch). It is extremely important to be consistent with where the label is placed relative to controls and displays in order to avoid confusion. Also it is extremely important to do this to avoid ambiguity. For example, if a label is placed between two controls or displays, it is not clear as to which control or display it applies.

*Principle 2: Use as few words as possible.* For example, a label for an engine boost pump we could place the words “Engine Boost Pump” above the word “On” above the switch, and “Off”

below it. Much more desirable, however would be to simply place the word “Boost” above the switch, and “Off” below. This is known as the “Kiss Principle” (Keep It Simple, Stupid). *Principle 3: Use block lettering with high contrast with the panel background and make sure the lettering is large enough to be easily read.* Guidelines and specifications for lettering design and size can be found in human factors/ergonomics textbooks and handbooks (e.g., Sanders & McCormick, 1993; Woodson, Tillman, & Tillman, 1992).

## TRANSFER OF TRAINING AND DESIGN OF CONTROLS AND DISPLAYS

### *Negative Transfer of Training*

One of the major causes of accidents is a mistake made as a result of learning how to accomplish a task with one type of display(s) or control(s), and then transitioning to a new system requiring similar tasks, but with a different display(s) or control(s) – or a system where the display(s) or control(s) has been placed in a different location. We humans are quite capable of learning to do it the new way *so long as we are consciously thinking about it*. However, when we are not thinking about it we are likely to revert back to the original way. This returning to the old way is even more likely to occur if the operator is under stress or handling a heavy workload.

Some years ago, while I was serving in the Air Force as a radar controller, I was directing an air defense fighter plane back into Suffolk County Air Force Base on Long Island, New York. It was very early morning and there was fog down to the ground. The pilot was approaching over the ocean from the south, heading north, and letting down from an initial altitude of 30,000 feet. I directed him to call in his altitude every 10,000 feet of decent. The pilot did this as he descended, and had just called in that he was passing through 10,000 feet. That was the last I heard from him! The plane was found in the ocean just off shore. It was clear from where the plane crashed into the ocean that the pilot had actually been passing through 1,000 feet when he last called in. It turns out that a new altimeter had been installed in the plane replacing the traditional 3-pointer altimeter. The 3-pointer altimeter has a short pointer for indicating 10,000-foot readings, a medium length pointer for 1,000-foot readings, and a long pointer for 100-foot readings. Thus, if you were at 21,300 feet, the short pointer on the 2 would indicate 20,000 feet, the medium pointer on the 1 would indicate 1,000 feet, and the long pointer on the 3 would indicate 300 feet. The pilot has to mentally integrate these three readings to determine that he is at 21,300 feet. Because humans are poor at rapidly and accurately doing these kinds of integration tasks, a new altimeter had been designed in which the 10,000-foot reading was made a direct digital readout at the bottom of the altimeter. Now, the shortest needle indicated 1,000 foot increments and the longest, 100 foot increments as before. The pilot, highly trained on the 3-pointer altimeter, dealing with the stress of letting down through fog on an early winter morning, apparently had reverted to the earlier learned “occupational stereotype”, and read his short pointer as 10,000 feet. That same mistake of failing to consider the negative transfer effects and putting this new two-pointer altimeter in these aircraft resulted in a number of fatal aircraft crashes before the problem was corrected. Unfortunately, I know of numerous instances where this kind of problem has killed people.

This is not to say you can never introduce a new control or instrument without having negative transfer effects. The key usually is that the new display or control has to be very different from the old one, so that they cannot be confused. For example, many aircraft use a

moving vertical scale, fixed pointer altimeter that is very easy to read and does *not* result in a negative transfer effect for persons who first learned to fly with the 3-pointer round dial type of altimeter.

### *Going From "A" to "B" Versus Going From "B" to "A"*

The example above brings up another important point relative to transfer of training and design of controls and displays. In the above example, we went from instrument "A", the three-pointer altimeter, to "B", the new vertical scale altimeter, with no negative transfer of training effects. However, persons who first learned to fly with "B" had a great deal of difficulty transitioning into an aircraft having the 3-pointer altimeter.

### *Stress Effects and Design of Controls and Displays.*

In designing a system of controls and displays for a workstation, it is important to keep in mind how stress, such as from a heavy workload, having to attend to several things at once, emergency situations, etc., effects humans. We already have noted the tendency to revert to previously learned ways of doing things when the new way has elements similar to the old way. In addition, it is important to recognize that, under stress, people experience a narrowing of attention and will only attend to the most obvious cues. In addition, when our workload becomes excessive, such as in emergency situations, we will become confused if there are too many signals or cues or control tasks requiring our attention. For these reasons, among others, it is important to place the primary controls and displays where they will most readily be seen and used, and make sure they are very easy to read, understand, and operate. The 3-mile island nuclear power plant disaster probably would not have happened if more attention had been paid to designing controls and displays for effective use in emergency situations.

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